High Resolution Geodetic Measurements of Co-seismic Fault-zone Deformation for PFDHA

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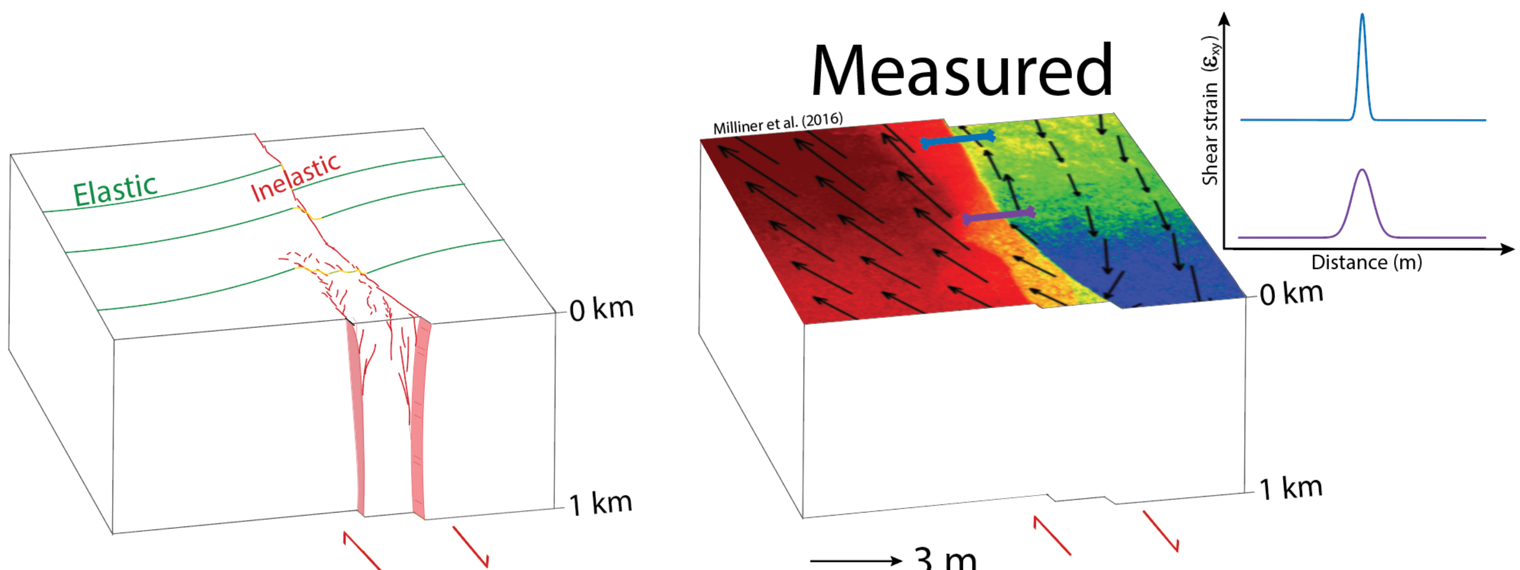
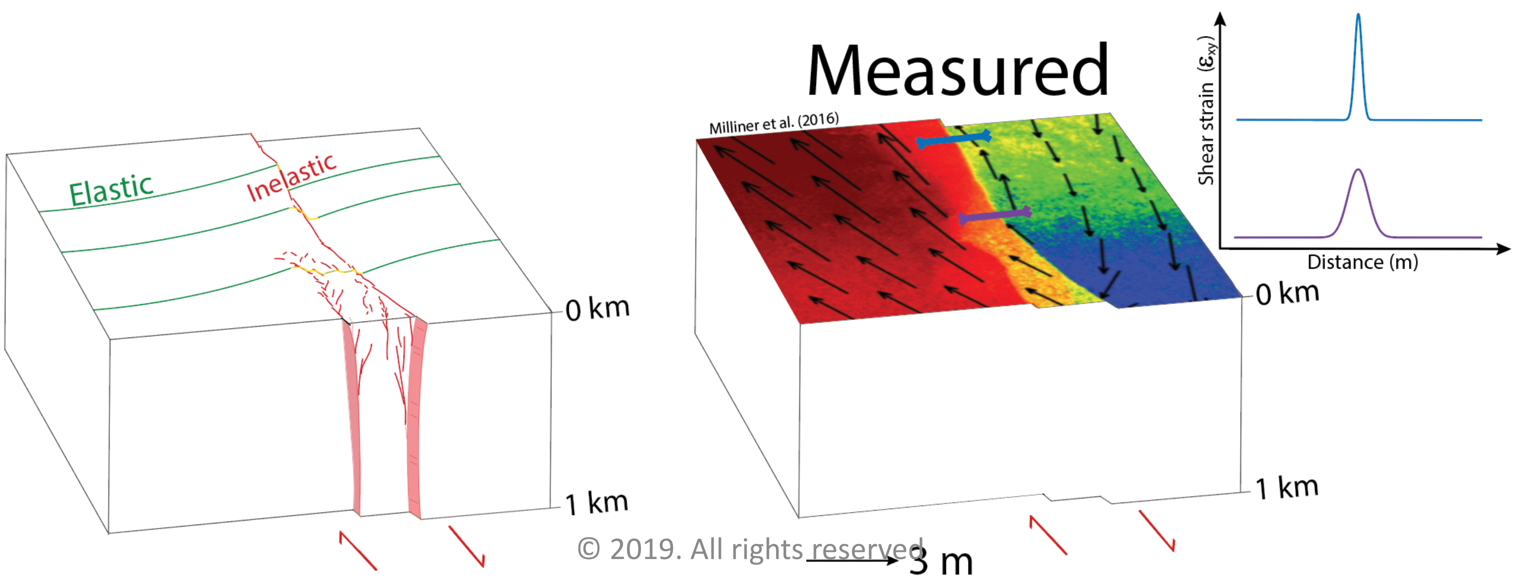


Introduction

- **Aim**: Use high-resolution geodetic data that can resolve near-field surface deformation to improve PFDHA models.
- **Motivation**: Measuring distributed faulting is highly challenging in the field (largely due to lack of cultural features that span the fault zone in perpendicular manner).
- **Method**: Use optical and SAR pixel tracking from multiple $M_w > 7$ surface rupturing earthquakes to measure distribution of strain across fault.

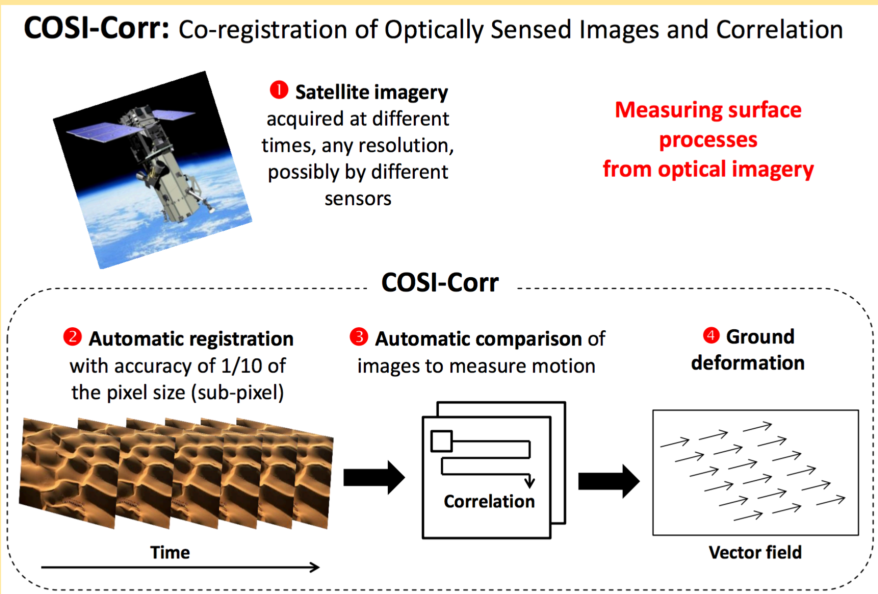


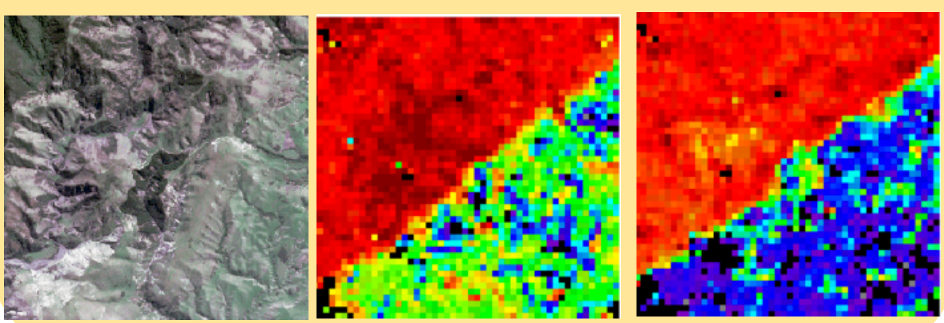
Multiple easrthquakes

Event	Year	Mw	Length (km)	# strain profiles	Mechanism
Landers	1992	7.3	80	~1000	SS
Hector Mine	1999	7.1	50	~700	SS
EMC	2010	7.2	120	500-1500	SS, normal
Balochistan	2013	7.7	240	30	SS
Napa	2014	6.1	30	30-150	SS
Kumamoto	2016	7.1	40	40	SS, normal
Kaikoura	2017	7.8	120	120-600	SS, thrust
Canterbury	2011	Mw 6.2			SS,
Norcia, Amatrice					SS, normal
China x ??? Gareth F.?					??
Papau New Guinea					thrust
Palu	2018	7.5	150	70-500	SS

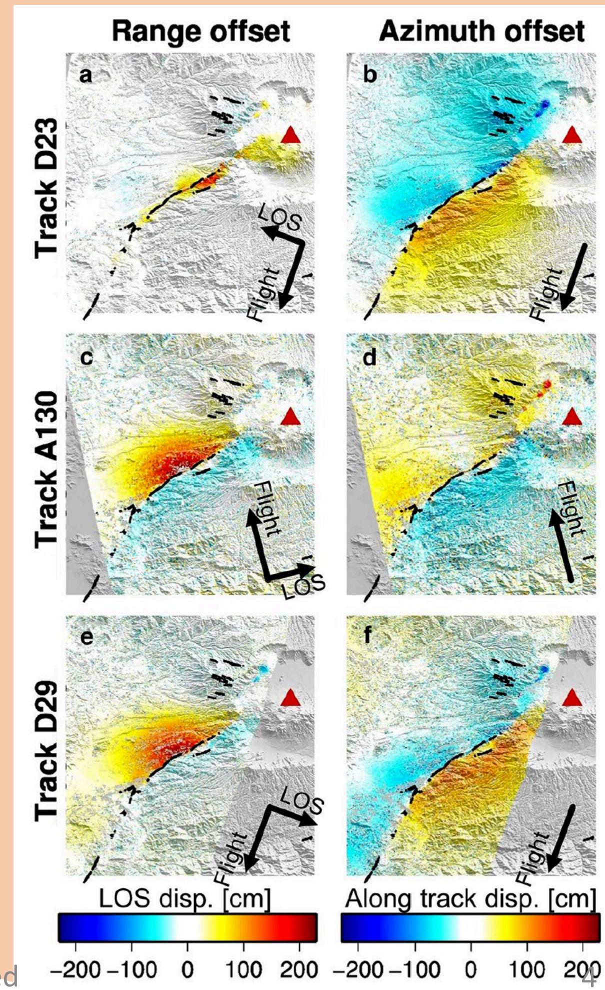
Methods: Optical & SAR pixel tracking

Correlate optical radiometric data (visible EM)



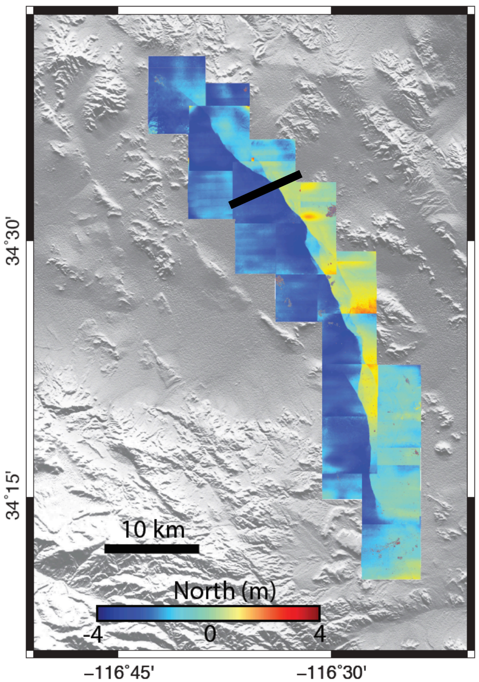


Correlate amplitude of radar backscatter (microwave EM) > 3 look directions → 3D motion

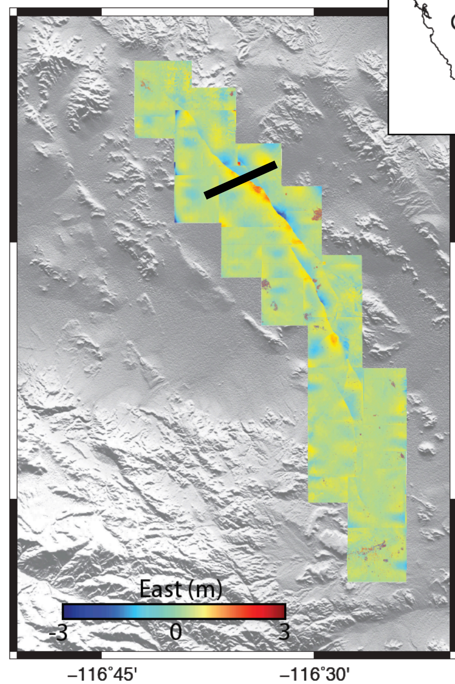


Results – Optical pixel tracking – 2D

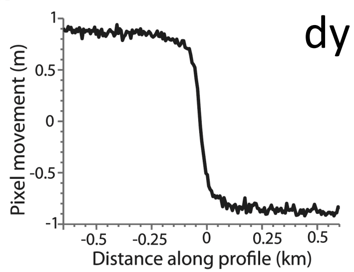
1992 Mw 7.3 Landers



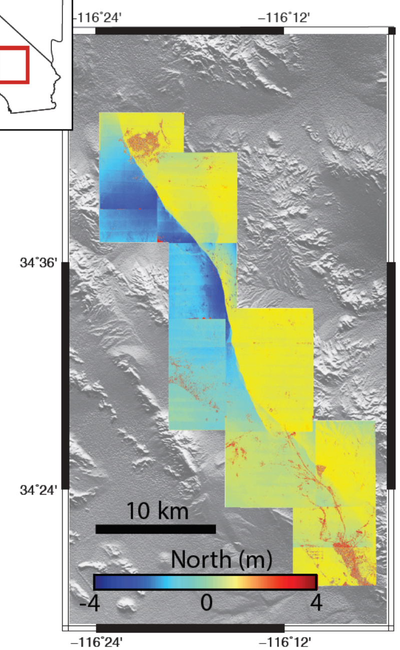
dx



dy



1999 Mw 7.1 Hector Mine



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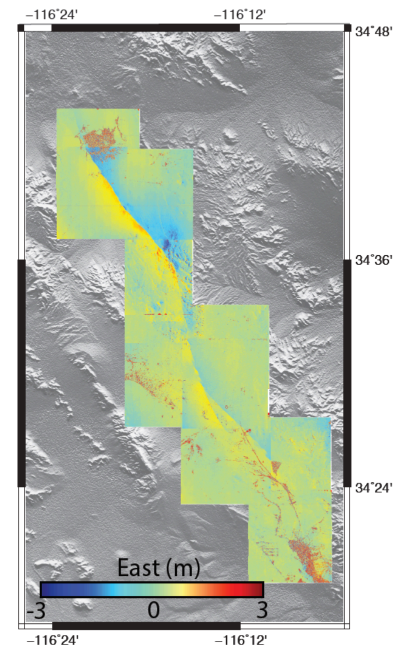


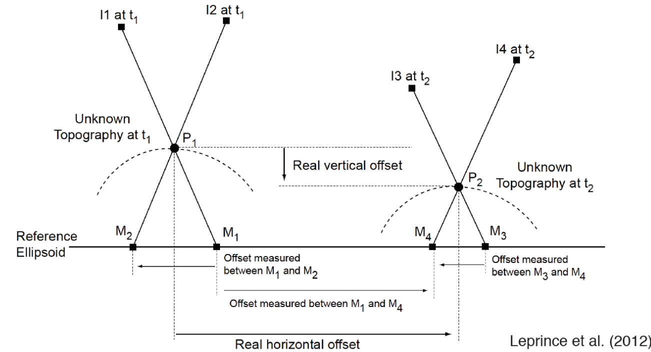
dy

Milliner et al. (2015)

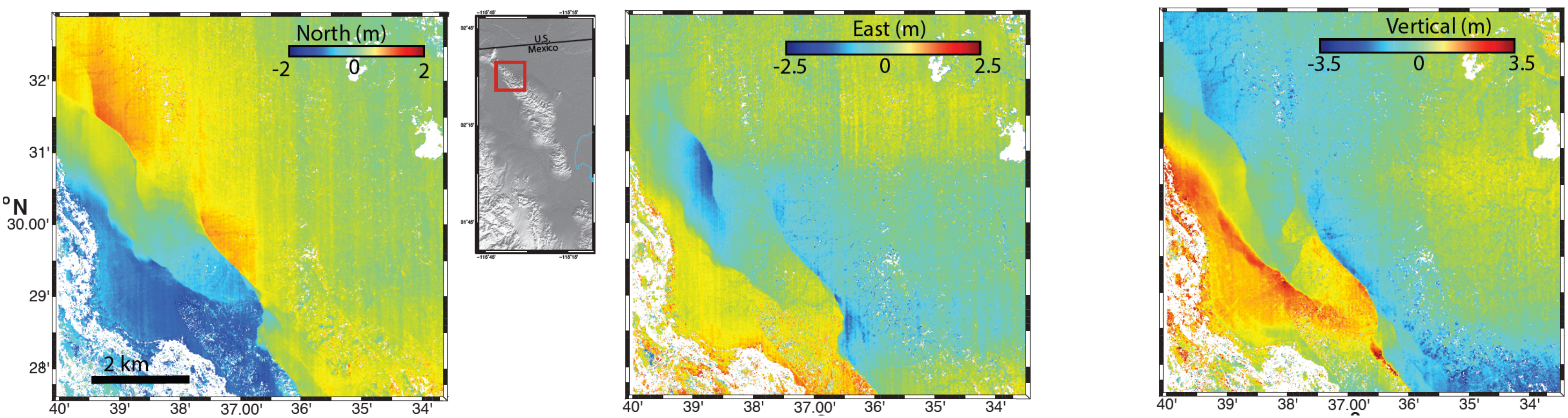
Milliner et al. (2016)

Results – Optical pixel tracking – 3D

- El-mayor Cucapah, M_w 7.2, 2010, Mexico
- Oblique: strike-slip, normal
- Rupture length: 120 km



2010 Mw 7.2 El-Mayor Cucapah



Leprince et al. (2015)

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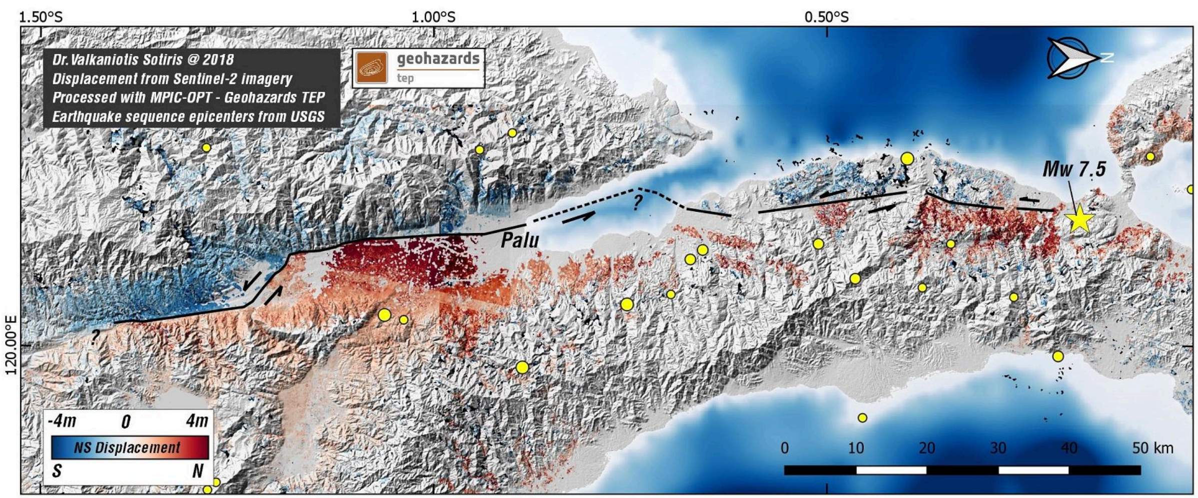
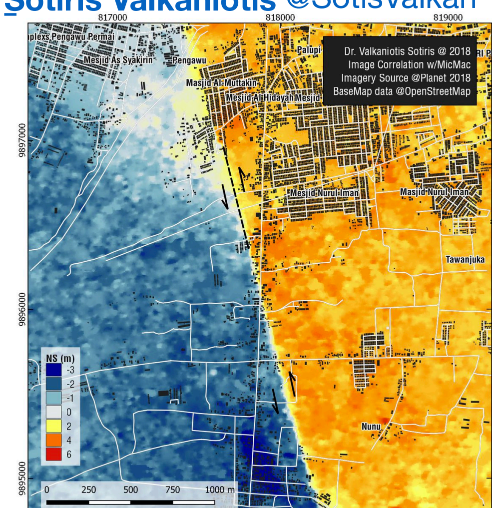
Palu, Indonesia, Mw 7.5

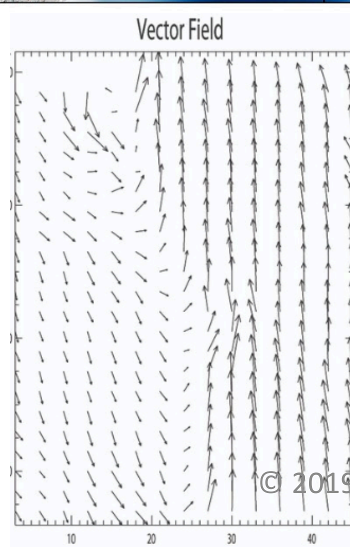
- 150 km surface rupture
- Sentinel 2 data

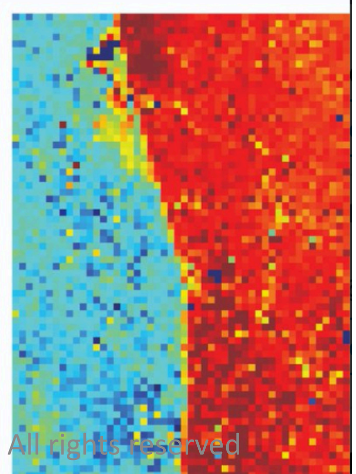


Sentinel 2 – 10 m resolution

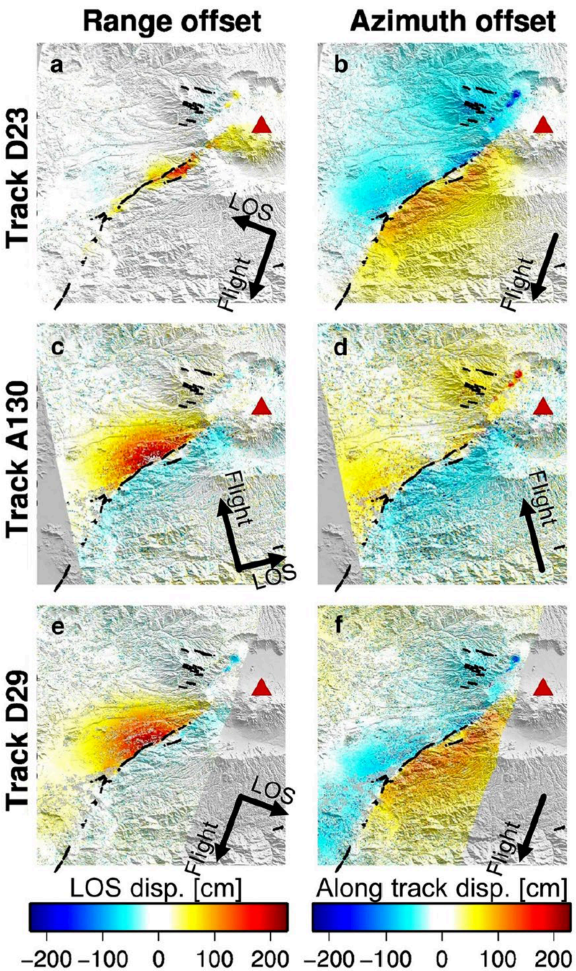
Sotiris Valkaniotis @SotisValkan



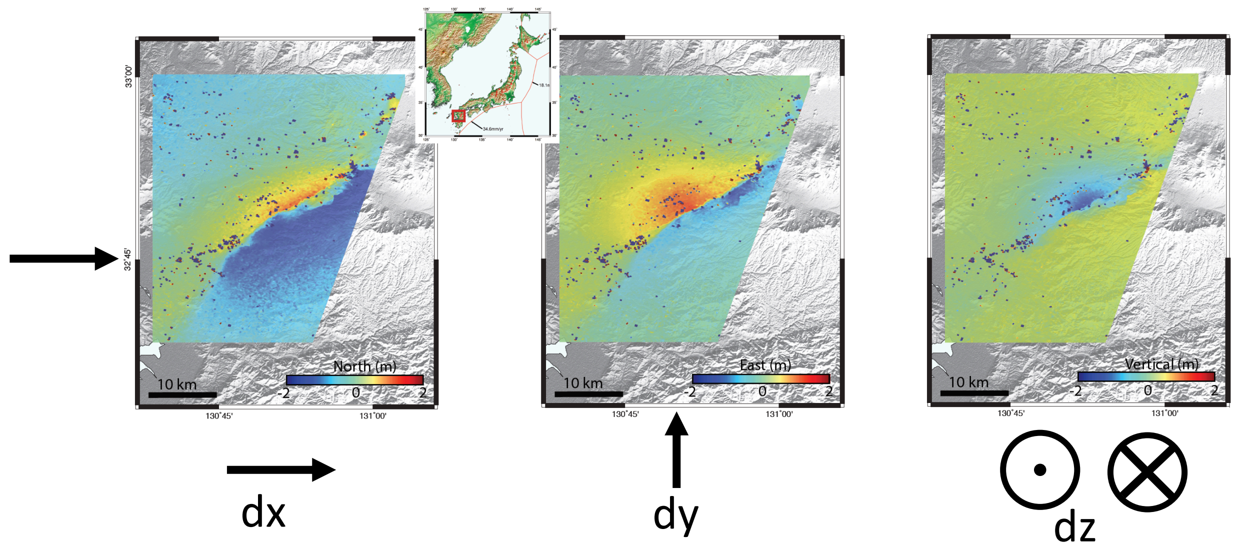




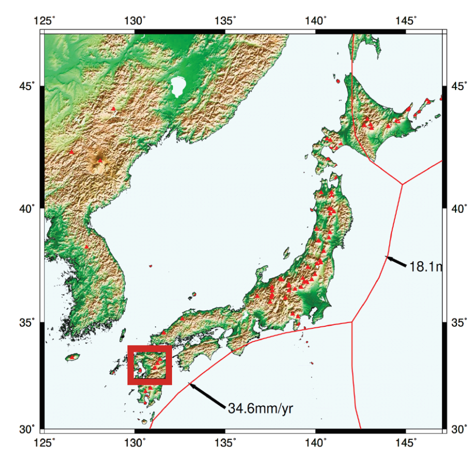
Radar pixel offsets – 3D



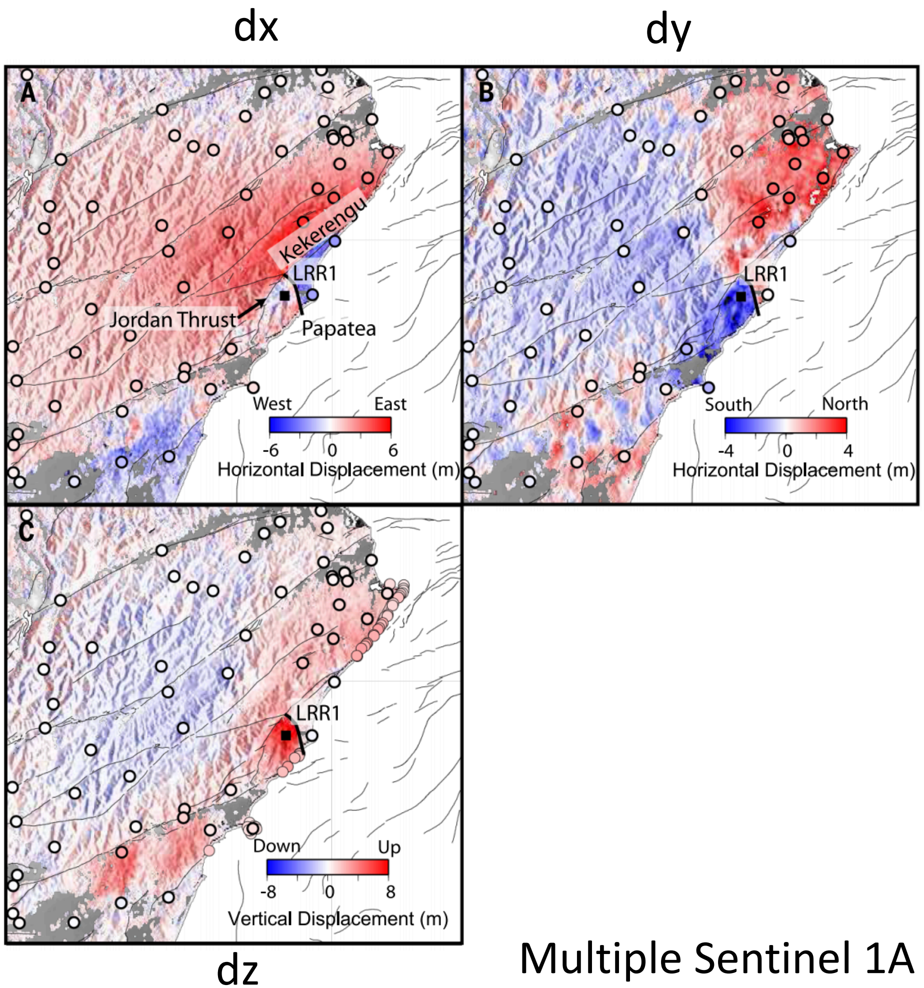
2016 Mw 7.1 Kumamoto



- Japan, 2016, Mw 7.1
- Oblique: Strike-slip, normal
- Rupture length: 40 km
- Noise level ~20 cm (1 sigma)
- Pixel resolution: ~25 m



2017 Mw 7.8 Kaikoura, NZ (?) – 3D SAR

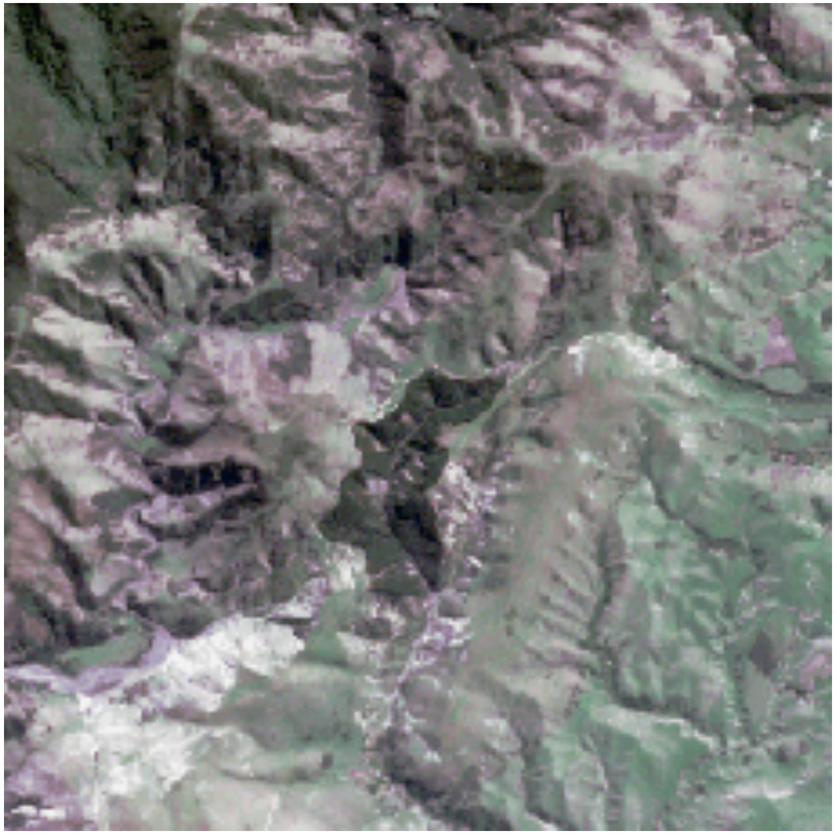


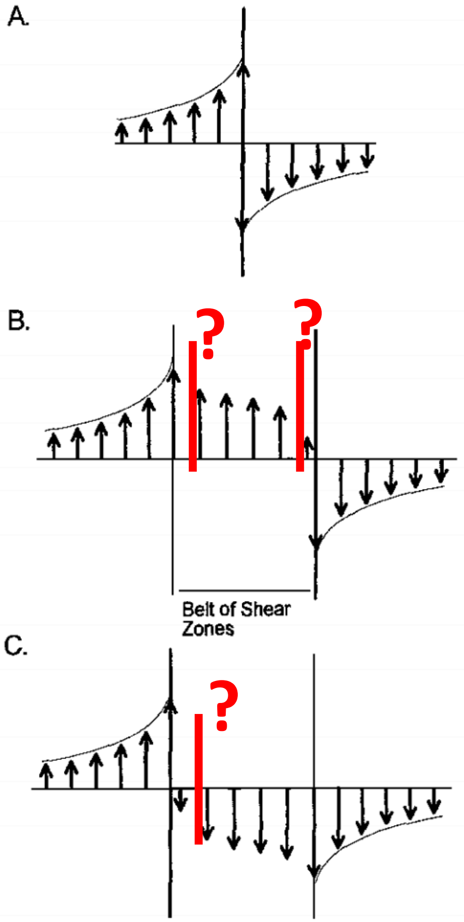
- Highly complex event, > 12 major faults.
- Underlying mega-thrust thought to participate, and perhaps primarily control rupture propagation and explain the large rupture complexity.
- Due to uniqueness of rupture, debate whether to include this in PFDHA?

Multiple Sentinel 1A (ESA) radar scenes,
C-band (3 cm wavelength)

Hamling et al. (2017)

How to calc. probabilities using geodetic data?





Johnson et al. (1994)

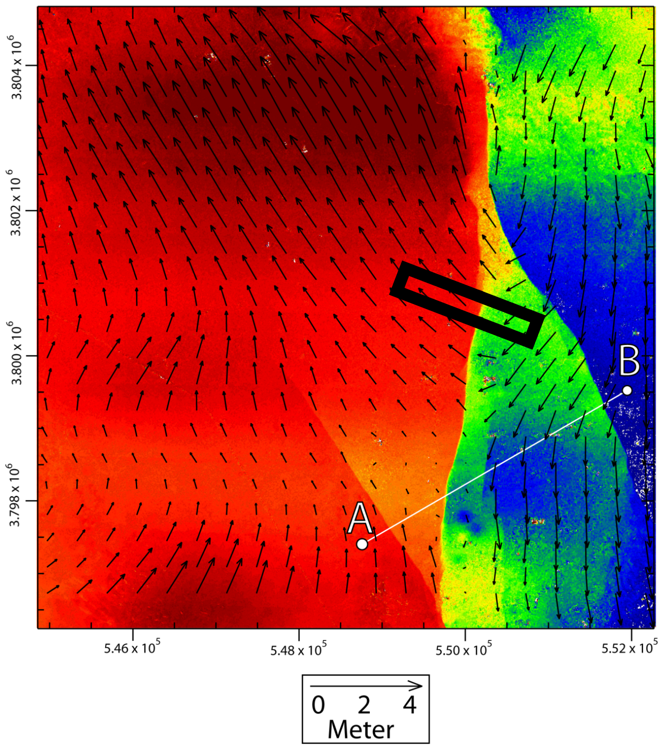
Key assumptions:

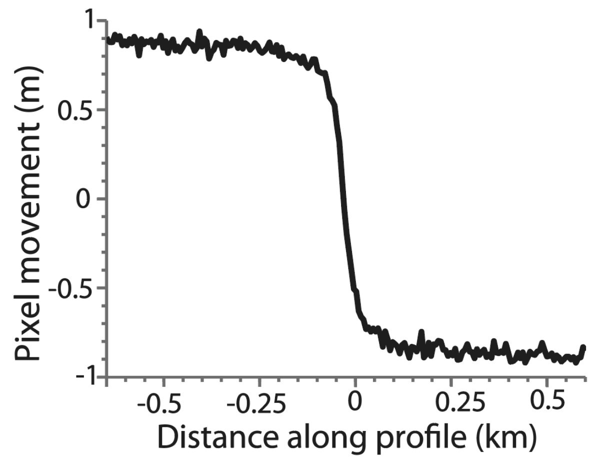
- We use strain, not displacement on indiv. fractures.
- Due to geodetic imagery averaging spectral properties over an area + corr. window → cant resolve individual fractures, the velocity field is almost continuous.
- Therefore product we'll provide is the amount of shear strain a structure will experience over a given length scale == total displacement.

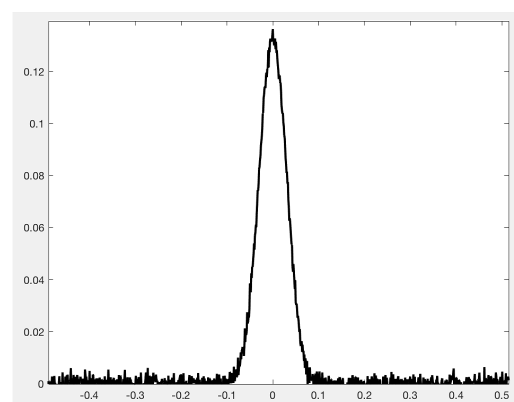
$$\lambda(\varepsilon \geq \varepsilon_o)_{xyz} = \alpha(m)\, P[sr \neq 0\,|m] \int_r P[\varepsilon > \varepsilon_{inelastic}|\, r, z]\, P[\varepsilon \geq \varepsilon_o|\, r, \varepsilon_{inelastic}]\, dr$$

Results - profiles

Vector Field Showing Ground Deformation at the Kickapoo Stepover



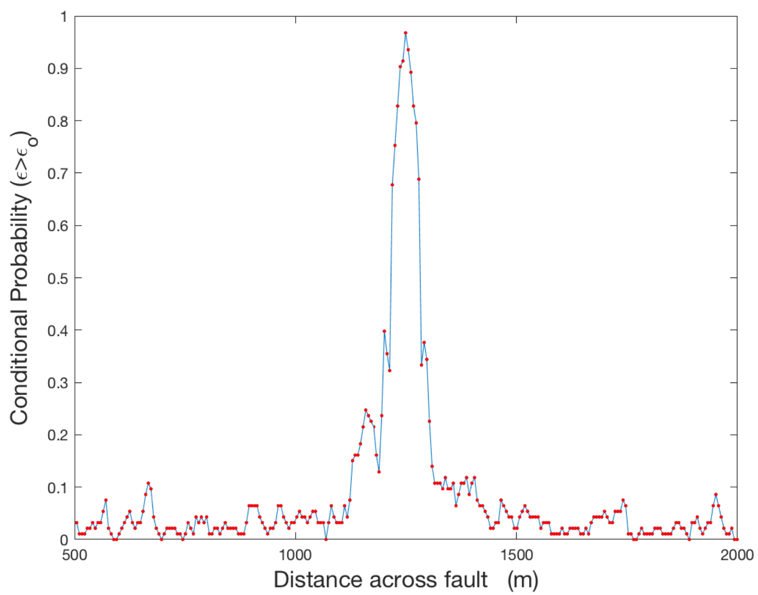


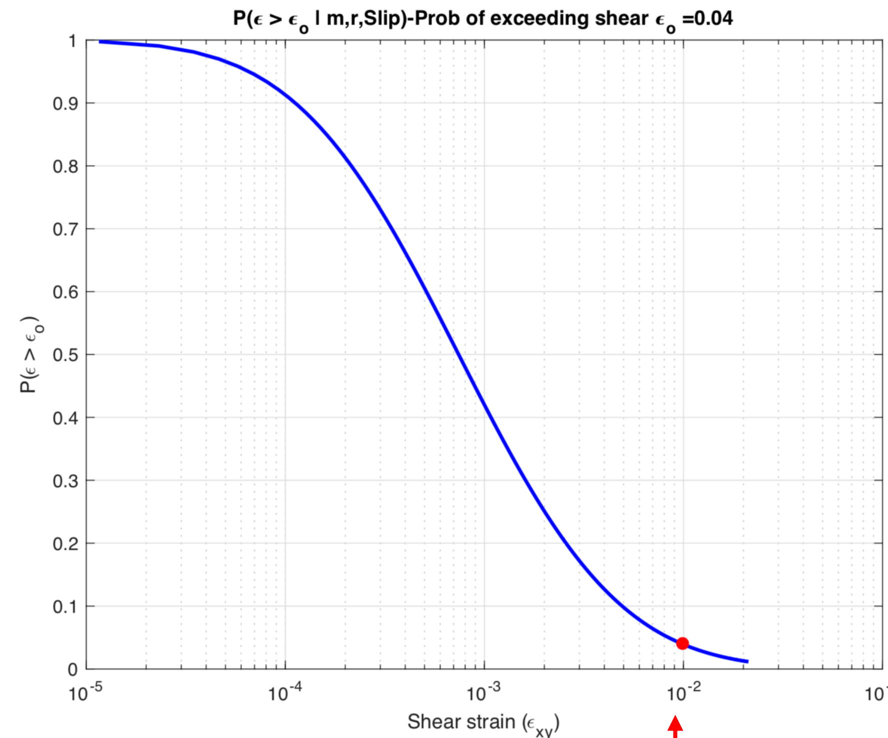


1. Draw stacked profiles perpendicular to fault (~200 m width) → fauzlt parallel motion
2. Calculate gradient → shear strain

Results - Probability calculation

4e-3 = yield strength of granite → conservative inelastic strain

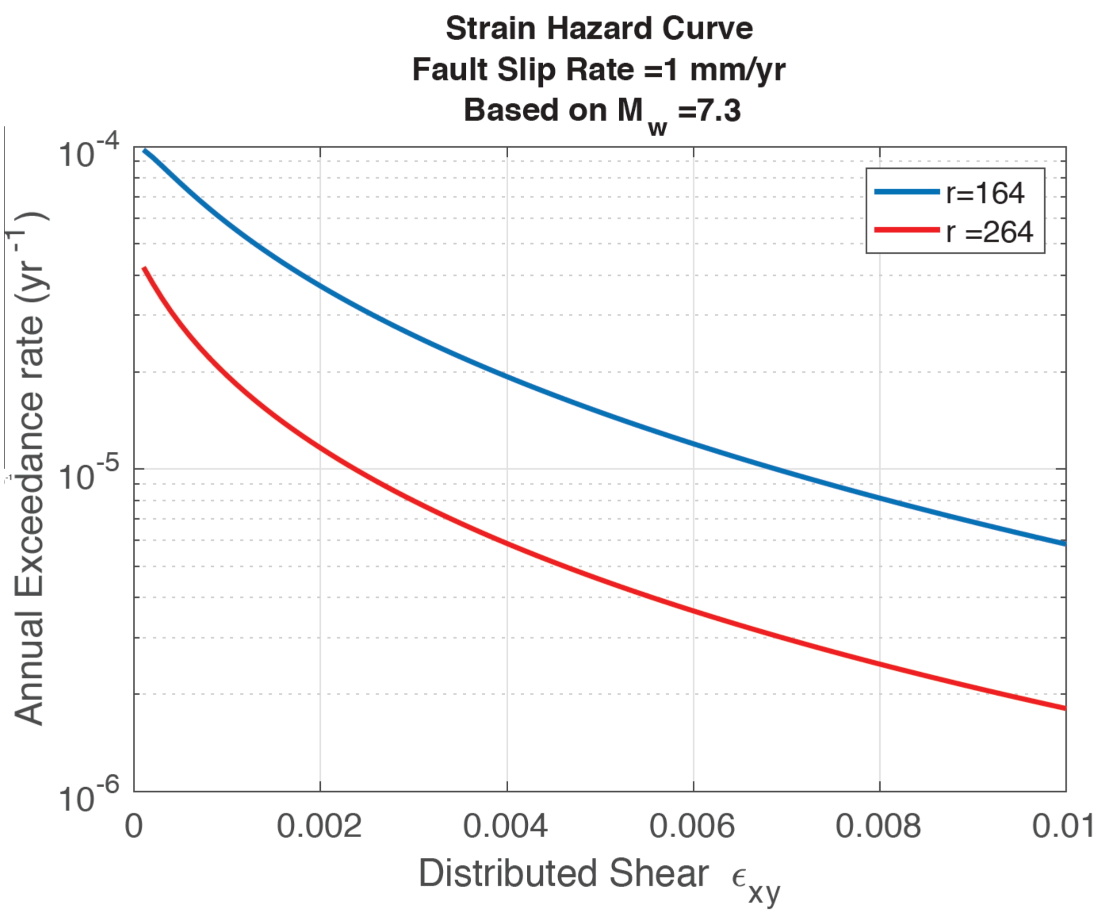




$$\lambda(\varepsilon \geq \varepsilon_o)_{xyz} = \alpha(m)\, P[sr \neq 0\,|m] \int_r P[\varepsilon > \varepsilon_{inelastic} |\, r, z]\, P[\varepsilon \geq \varepsilon_o |\, r, \varepsilon_{inelastic}]\, dr$$

Similar to Petersen et al. (2011), but using strain

Results – Hazard curve



Scenario event:

- Assuming fault slip rate = 1 mm/yr
- Magnitude = 7.3

- Hazard of strain for 2 distances from main rupture.
- Another key assumption:
  - Location of primary rupture has been identified (with confidence from trenching) uncertainty on location not considered

Conclusions

- **Aim**: outline a standard method for high-res geodetic data to constrain PFDHA models.
- **Results**: Geodetic data allows us to gather thousands of strain profiles.
  - Potential to do PFDHA for SS, normal + thrust
- **Assumptions& Limitations:**
  - We quantify strain, not displacement on individual fractures.
  - Can’t discern elastic vs inelastic, we have to assume a threshold value that exceeds yield strength, or can let user decide the minimum strain to exceed.
  - Data of varying resolution + noise → varying sensitivities to strain.

Future work

- **Going forward:**
  1. Most data already gathered
  2. More eq's (1-4)
  3. Include Kaikoura?
  4. Separate oblique faulting events?
     1. Decreases number of data per faulting style
  5. Asses whether near-surface geology, fault geometry, sediment thickness etc… has an effect → this could reduce epistemic uncertainty.
- **What we need (data):**
  - 2018 M_w 7.5 Palu, Indonesia – Planet labs (free)
  - 2013 M_w 7.7, Balochistan, Pakistan – Landsat (free)
  - 2014 M_w 6.1 Napa, US – lidar, optical (pre-existing)
- **Timeline:**
  1. Will verify PFDHA code with Rui Chen - visit Sacramento next month.
  2. Process more data (<2 months).
  3. Publish, < 1 yr timeframe - a method detailing how to use geodetic data for PFDHA + present results from multiple earthquakes.